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A
LETTER

FROM

M. CHRISTIAN MAYER,

Aſtronomer to the Elector Palatine,

To Mr. N. N.

On the Going of a New Pendulum Clock,

MADE BY

Mr. JOHN ARNOLD,

AND

Set up in the Elector's Obſervatory at *Manheim*.

(Tranſlated from the German.)

LONDON:
Printed for T. Becket, Corner of the *Adelphi*, *Strand*.
MDCCLXXXI.

1781

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BRITISH MUSEUM 30 NOV 71

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PREFACE.

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SINCE the revival of the ſciences in Europe, one of the great Deſiderata of aſtronomers was to have proper inſtruments for the menſuration of time. The numerous contrivances of *Tycho Brahe, Kepler* and others, ſhew how eagerly they ſought after this object; and if their inventions loſe much of their former merit by being contraſted with later improvements, they evince the neceſſity, and ſhew at leaſt the progreſs of ſo uſeful and deſirable an art. That the longitude might be found if Chronometers could be brought to perfection, was long ſince well known to geographers; even the method of determining it by the moon, ſo lately introduced into our navy, was pointed out more than two hundred years ago by *Peter Appian*; but this method required a perfect theory of the moon's motion, which could not be found without obſervations; and as thoſe obſervations alſo required an exact knowledge of time, it is rather extraordinary that ſcarce any thing was done towards the improvement of time-pieces for more than a century; it is ſtill more remarkable, that after *Dr. Hooke*, *MM. Huygens*, and *Leibnitz* had made ſuch diſcoveries as rendered clock and watch-making a trade; yet, among the thouſands of people employed in that branch ever ſince, ſcarce any have made any real improvements, except Meſſrs. *Graham*, *Harriſon*, and *Arnold*.

Of all faculties of the human mind, the moſt ſcarce and valuable is invention. Artificers may drudge on in the ſame dull path for ages; compilers may fill the world with books, and make a great ſhew of erudition by publiſhing the *crambe recocta* of former writers; but the diſcovery of a new property in ſcience, or the detection of one ſingle principle in nature, unknown before; is a much greater addition to the general ſtock of knowledge: it is this intuitive readineſs of diſcovering new principles, or the eaſieſt and ſimpleſt methods of applying the old; that has rendered the time-pieces of *Mr. Arnold*, ſo greatly ſuperior to thoſe of former artiſts, and which from their being introduced into our navy, promiſe fair to become of the greateſt national importance.

It is very proper that the world ſhould from time to time be informed of ſuch inventions and improvements as appear to be of general utility; both on account of the public benefit and that of the inventor; this was doubtleſs the author's motive for writing the following piece, and is equally ſo of his tranſlator; the reader will judge from the performance of this excellent machine recounted hereafter, how valuable the principles muſt be from whence it derives ſuch extraordinary accuracy; but as the author has omitted one of the moſt material parts in the conſtruction of the pendulum, which in my opinion ſhews the ingenuity of the inventor, and conduces to the perfection of the whole, as much as ſeveral others that have been deſcribed; I ſhall take the liberty of ſubjoining a ſhort account of it.

The nature of the gridiron pendulum is too well known to need any particular explanation here; it is kept continually of the ſame length, under the different viciſſitudes of heat and cold, by the counteraction of bars of different metals: *Mr. Arnold's* pendulum conſiſts of *five* bars: this number I am well aware, has been condemned as impracticable by *Mr. Cummings* in his treatiſe of clock work; but experience has demonſtrated the contrary to be true. In the common conſtruction, the rod uſually paſſed through the ball, which was elevated or depreſſed thereon, by means of a ſcrew; this was a conſtant ſource of error; for on every change of heat and cold though the middle rod was invariable, the center of oſcillation of the ball kept fluctuating continually: *Mr. Arnold* therefore conſidered, that if the rod was faſtened to the loweſt part of the ball, the center of oſcillation would move upwards when the ball expanded; and that if it was faſtened to the top, the center would deſcend; he therefore concluded, that there muſt be ſome intermediate point,* to which if the rod was faſtened, the center of oſcillation would be ſtationary, whether the ball ſhould expand or contract. The buſineſs was therefore reduced to the ſolution of a Geometrical Problem; an anſwer to which *Mr. Arnold* received from the Rev. *Dr. Maſkelyne*; and the ſame was alſo reſolved by *Meſſrs. Vince, Burrow,* and others.

The introduction of ruby pallets and cylinders into clock and watch work, to take away the effects of oil, holds a capital rank among modern improvements. *Mr. Harriſon* tried a number of methods to get rid of it, but it ſeems without ſucceſs; for oil was uſed in the celebrated watch for which he obtained the 20,000£. After rubies had long been made uſe of by *Mr. Arnold*, and found to anſwer his utmoſt expectations; it was propoſed by a perſon of no ſmall eminence in the world, to employ agates inſtead of rubies: unfortunately that gentleman happens to be miſtaken in his conjectures; for it has been proved by experience that agates are much too ſoft to anſwer the purpoſe of Rubies. As to the theories that ſome authors have attempted to give, reſpecting the nature and tenacity of oil, and its alteration by heat and cold, it is evident they never can anſwer, ſince they are all founded on a ſuppoſition that the oil conſtantly retains its fluidity; but it is well known that part of the oil gradually hardens and becomes ſolid, and by its adherence to the parts of the machine, introduces friction, increaſes the irregularities, and prevents the parts of the movement from following any of the laws which thoſe theoriſts have ſuppoſed; therefore the only eligible method was to get rid of it entirely; at leaſt in ſuch parts of the machinery as are moſt liable to be affected by its variation or coheſion: this was the primary motive for ſubſtituting rubies; and it is doubtleſs in conſequence of this, and other* judicious alterations, that *Mr. Arnold's* time-keepers are ſo much ſuperior to thoſe of other artiſts.

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* This point is neither the "*Center of Gravity*" nor of oſcillation.

It is uſual for people of a contracted diſpoſition to vilify ſuperior abilities, and depreciate inventions they are unable to equal. No ſooner had Mr. *Arnold* propoſed to add ruby pallets to *Graham's* famous clock at the Royal Obſervatory, but many of the *London* watch-makers inſtantly condemned the propoſal. One ingenious author in particular, boldly aſſerted, *ex cathedrâ*, that if the propoſal was carried into effect, the clock would ſtop in leſs than a month: the alteration however was made; and, notwithſtanding this prediction, the clock has been going ever ſince, and has kept time incomparably better than it did before, though it is now near ten years ſince the pallets were applied.* With equal confidence, and much leſs regard to truth, it was alſo aſſerted, that Mr. *Arnold* faſtened the parts of his watches together with ſealing-wax.† I ſhould ſcorn to take notice of ſuch a ridiculous calumny, had it not been induſtriouſly circulated to Mr. *Arnold*'s prejudice, and even carried to the ears of one of the greateſt perſonages in the kingdom.

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* The Elector's clock as well as others made by *Mr. Arnold* have cycloidal cheeks.

It is greatly to be lamented, that the few Obſervatories in *Europe* are not better provided with time-keepers and inſtruments of the moſt exact conſtruction. There are ſtill many material points in aſtronomy to be ſettled, and irregularities among the celeſtial bodies whoſe cauſes are yet undiſcovered, which probably might be inveſtigated if greater exactneſs was employed in the obſervations. The variation of the places of ſeveral of the fixed ſtars, and the difference between the computed and obſerved longitudes of the moon and planets, notwithſtanding the late improvements, make this more than conjectural; and it is much to be regretted, that aſtronomers have it not in their power to make farther and more accurate attempts, by being better provided with inſtruments. To furniſh ſuch additional encouragements to ſcience, is beyond the abilities of moſt private perſons; but, when conſidered as a national expence, it is of all concerns the moſt trifling. Unfortunately the examples of our gracious Sovereign and the *Bavarian* Elector are more admired than imitated.

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* Vide Dr. *Maſkelyne*'s Obſervations.

† The pallets of Mr. *Graham*'s clock at the Obſervatory; of that of the Elector of *Bavaria*, and alſo thoſe of that excellent Chronometer whoſe rate of going was lately publiſhed; were all fixed in with the ſame *cement* which this critical gentleman has been pleaſed to call ſealing-wax!

While Mr. *Arnold*'s improvements in clock-work may thus become ſerviceable to aſtronomers; that ſuperior degree of perfection to which he has brought his Pocket Chronometers muſt be of the higheſt utility in geography and navigation. The difficulties, dangers, and loſs of time, which in hazy weather at ſea were formerly inevitable; are now, for the greateſt part, happily removed: ſhips now may proceed on their voyages with a degree of certainty and expedition unhoped for and unknown to preceding navigators; and though geography is at preſent in a very imperfect ſtate, yet, from the aforeſaid exertions of genius, we have reaſon to expect that as ſoon as the uſe of Chronometers become general, we ſhall find it attended to as it properly deſerves, and ſee it flouriſh equally with the reſt of the ſciences.

THE TRANSLATOR.

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A Letter from M. CHRISTIAN MAYER, Aſtronomer to the *Elector Palatine*, to Mr. N. N. on the going of a new Pendulum Clock, made by Mr. JOHN ARNOLD, and ſet up in the Elector's Obſervatory at *Manheim*.

AFTER a period of four months, I am at laſt enabled to ſatisfy your earneſt deſires: you already know that I am indebted for this excellent inſtrument to the generoſity of our great Elector, and the kind offices of the celebrated *Dr. Maſkelyne*, Aſtronomer Royal at *Greenwich*. It was left to *Dr. Maſkelyne* to chuſe whom he pleaſed among the many famous artiſts in *London*, and he gave the preference to *Mr. Arnold*, intimating that he would make trial of the Clock at the Obſervatory at *Greenwich*, before he ſent it to *Manheim*; which accordingly was performed, and I received it only about the end of *Auguſt* laſt year, 1779, after it had been tried by *Dr. Maſkelyne* above ſix months.

To my great ſatisfaction, I found the extremities of *Graham's* 'ſcapement ornamented with two diamonds, where they touch the wheel. *Dr. Maſkelyne* in a letter has aſſured me, that the axis of each wheel * turns in a hard ruby, not for ornament, but from neceſſity; theſe ſtones in ſome meaſure ſupplying the place of oil which is uſually applied to clocks, in order to leſſen the friction. The pendulum rod and the ball, are quite on a new conſtruction, which I have never yet found deſcribed; I call it *new*, becauſe the ordinary grate, or gridiron pendulum, as it is called, compoſed of ſeveral metal bars, is here intirely omitted, and the lens or ball itſelf, which has a ſection in the middle of about two fingers breadth, preſerves its center immoveable in all variations; ſo that the effects of heat and cold by lengthening and ſhortning the rod of the pendulum, are manifeſtly annihilated; and on the other hand, the reſiſtance of the air is diminiſhed. But, inſtead of all deſcription, come and ſee the inſtrument.

I ſhall now proceed to anſwer your important queſtions; namely, what faults and inaccuracies I have obſerved in the inſtrument; my method of making the experiments; and the conſequences I deduce from them.

In order to try the clock, I made uſe of the fixed ſtars over the meridian, and have ſcarce omitted any, whoſe paſſage I could obſerve by night or by day, with the large fixed Mural Quadrant, from 1ſt, *September* 1779, to 10th. *January* 1780:

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* This is an overſight: it is the ſwing wheel only that is jewelled.

It is needleſs here to repeat the names of thoſe ſtars I obſerved, as it ſeems *Dr. Maſkelyne* has prevented me from giving you any new information on that head.

I preferred the tranſits of the ſtars, becauſe I thus obtained a far greater number of experiments proper for trying the clock, than if I had confined myſelf entirely to the obſervations of the ſun. At the ſame time, I was enabled to avoid another important objection ariſing from the variable deviation of the ſun, if the points of diviſion of the mural arch do not lie exactly in the ſame plane; I therefore divided the whole time, from 1ſt *September* to 10th. *January*, into nine portions, *viz.* from 1ſt. *September* to 16th; from 16th. *September* to 1ſt. *October*; and ſo on to 10th. *January*; I compared the time of the paſſage of the ſtars of the 1ſt. *September*, with the time of the paſſage of the 16th, and divided their difference by the number of days, which gave me the mean motion, and the rate of the clock for the ſpace of fourteen or fifteen days: in the ſame manner I proceed with *Reaumur's* thermometer placed cloſe by the clock, and marking down the degrees, I had obſerved for fourteen or fifteen days, added them into one ſum, which divided by the number of obſervations, gave me the medium of cold and heat during that fortnight: I found the greateſt variation of the heat and cold that had happened during that fortnight, by taking the difference between the higheſt and loweſt degree. The ſame method I obſerved alſo with the barometer: It fortunately happened, that the variation in the paſſage of the ſtars, produced by the aberration of the light, the nutation of the earth's axis, and the preceſſion of the Equinoxes, was too inconſiderable in the ſpace of fourteen or fifteen days to be at all taken into the account, by reaſon of their oppoſite effects.

For inſtance, the difference between the aberration of the light, and nutation of the earth's axis was 15th *September* at α, of the Eagle 3″ 7, the effect of the Equinoxes + 1″ 7, conſequently this ſtar, from the 1ſt to 16th *September*, ſhould come two ſeconds ſooner to the meridian, a ſpace of time too minute to be diſcerned, and therefore not to be taken into the account.

They were almoſt equally inſignificant in the obſervations made upon γ and β Aquilæ, β and α Lyræ and δ of Antinous, all ſtars which I had taken from 1ſt *September* to 16th, at three different threads of a micrometer, fixed in a teleſcope of eight feet long, and of which I was able to make eighteen different compariſons, in order to meaſure the going of the pendulum clock, during a fornight.

This method enabled me to unite my obſervations, and and thoſe of my colleague, *Mr. John Mezger*, in a ſmall table which I have here the honor to preſent to you. The firſt column on the left hand ſhews the daily motion of the clock, reckoned in this manner, the expreſſion 24^{h}. — 0″,923 ſignifies that *Arnold's* Clock from 1ſt. *September* to 16th, ſhewed in its daily motion, 24 ſiderial hours *minus* $\frac{1}{10}$ of a ſecond. The expreſſion 24^{h}, − 1″ which you read at the 16th *September* to 30th, is to be underſtood that the daily motion of the pendulum, was 1 ſecond leſs than the 24 ſidereal hours; the ſigns + and — with the ſubjoined decimal numbers ſignify the rate that the clock goes too faſt or too ſlow each day. The other columns are ſufficiently explained by what has been ſaid.

Table of Compariſons of the Obſervations, made on Mr. Arnold's *Clock, from* 1ſt September 1779, *till* 10th January 1780.

Daily motion of the Clock.					Mean Deg. of heat according to Reaumeur.	Greateſt Alteration of Heat.
Hours.	″				Degree	Degree.
24	−0,923	from	1 *Sept.*	16	+18,0	3,6
24	−1,04	—	16 —	30	+16,8	2,3
24	−0,916	—	30 *Sept.*	16 *Oct.*	+14,1	4,9
24	−0,738	—	16 *Oct.*	1 *Nov.*	+14,06	3,0
24	−0,19	—	1 —	14	+10,1	4,0
24	+0,112	—	14 —	28	+ 7,2	3,5
24	+0,223	—	28 *Nov.*	16 *Dec.*	+ 6,8	3,0
24	+0,270	—	16 —	1 *Jan.*	+ 6,1	5,0
24	−0,172	—	1 —	10 *Jan.*	+ 2,74	3,2

In the ſame manner I have eſtimated the mean height of the barometer after the *Pariſian* rule, together with its greateſt alterations, and formed them into the following table.

From

Mean height of Barometer					Inches	Lines	Greateſt Alteration Lines
From	1 *Sept.*	to	16	——	27	6,8	6,
	16 ——	—	30	——	27	6,3	3,5
	30 *Sept.*	—	16	*Octr.*	27	7,3	5,1
	16 *Octr.*	—	1	*Nov.*	27	9,4	3,0
	1 *Nov.*	—	14	——	27	6,9	8,0
	14 ——	—	28	——	27	1,9	6,2
	28 ——	—	16	*Decr.*	27	6,1	8,8
	16 ——	—	1	*Jan.*	27	4,2	14,3
	1 ——	—	10	——	27	9,3	5,2

From both tables you have the mean ſtate of the air, and at the ſame time the mean motion of the clock, I muſt only obſerve that the higheſt degree of heat, 1ſt *September*, was 21 degrees, and in *January* the cold within the obſervatory, was at *Reaumeur's* freezing point; but in the open air on 8th *January* it ſtood 8½ degrees below the freezing point.

You well know, that according to the experiments hitherto made, a change of 20 degrees in *Reaumeur's* thermometer makes an alteration of nearly 16 ſeconds in the daily going of common pendulum clocks; but the firſt table given above, proves that ſuch alteration from 1ſt *September* to 16th *December*, amounted only to 1″,119, and yet this was the greateſt that happened in one hundred thirty one days, as appears from a compariſon with the reſt: a thing almoſt incredible, and which does the greateſt honor to the *Engliſh* Artiſt, *Arnold!*

The famous *Short*, was ſurprized at a ſimilar inſtance, in 1753; he relates in the Philoſophical Tranſactions, that his pendulum altered only one ſecond from the 22d of *February* to the 6th of *May* 1753, being the ſpace of ſixty nine days, and in *England* the heat cannot, during this period have altered much more than 10 degrees; but *Arnold's* pendulum according to the above obſervations, altered ſcarce more than 1 ſecond, though the heat varied 20 degrees: it likewiſe appears that *Arnold's* Clock ought to be greatly prefered to the famous machine of *Shelton*, which the *King* of *Great Britain* preſented to the celebrated Profeſſor *Kæſtner*, for the Obſervatory at *Gottingen*, which *Mr. Kæſtner* writes, went near 2″,1 ſlower in *Auguſt*, than in *January*, tho' he does not take upon himſelf to affirm it with certainty.

If it be admitted that heat and cold alone, diſorder the motion of the pendulum, it may be determined in the following manner, from the firſt mentioned table, how much the variation of one degree of *Reaumeur's* thermometer alters the going of this clock; I deduct the daily motion of the clock from the 1ſt to the 10th *January*, 24 — 0″,172 from its daily motion from the 1ſt to the 16th *September*, 24^{h} − 0″,923; alſo *Reaumeur's* degrees for *January* 1, *viz.* 2,74 from 8,18, the degree for *September*, the difference of the going of the clock is 0″,751, and the difference of the heat is 15,26 degrees, and dividing the former from the latter, the quotient 0,0492 ſhews the alteration of the motion of the clock, for each degree of *Reaumeur*. Thus may be conſtructed, the following third table, which ſhews the variation of *Arnold's* clock, for each of *Reaumeur's* degrees, when influenced only by heat and cold.

Degrees.	Deviation.
1	0,0492
2	0,0984
3	0,1476
4	0,1968
5	0,2460
6	0,2952
7	0,3444
8	0,3936
9	0,4428
10	0,4920
11	0,5412
12	0,5904
13	0,6396
14	0,6888
15	0,7380
16	0,7872

According to this table, the clock ſhould have gained upon a ſtar, from the 16th to the 30th *September*, about 0″,050, but according to actual obſervations it has loſt about 1″,04, the error therefore was, 0,12, from 15 *October* to 1 *November*, when the mean heat was 14 degrees, her daily motion ought to have been (according to ſiderial time) 24 — 0,727, but it was 24 — 0,738, ſo that the clock was too ſlow, by about the 100th part of a ſecond: from *November* 1ſt to the 14th, when the mean heat, ſince *September* 1ſt had already decreaſed 8 degrees, according to our table, the daily motion of the clock ought to have been 24 — 0,53, but from obſervations it it was 24 — 0,19, ſo that the clock was 0″,34 too faſt: from 14th *November* to the 28th, when the heat was 11 degrees leſs than *September* 1ſt, the clock ſhould have gone faſter about 0″,541 in 24 hours, and by obſervations, it gained about

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about $0'',27$, on account of the difference of 12 degrees, the clock ſhould have gone faſter towards the end of *December*, about $0'',59$ in 24 hours, than 1ſt *September*; and obſervation proved that every day it went too faſt by about 0,6 till the beginning of *January*.

From theſe obſervations, and the compariſons above made, (and more of a like kind might be drawn from the above mentioned table) are we capable of forming a juſt concluſion, with regard to the faults and errors of this remarkable pendulum clock? eſpecially as moſt of our learned men agree, in aſcribing the variation of its going ſolely to the heat and cold, and charge the reſt to the artiſt?

But the obſervations in table 1ſt, ſeem entirely to refute this univerſal received opinion: you there ſee that the mean degree of heat, from 1ſt *September* to 1ſt *November*, has decreaſed about 8 degrees, and that from 1ſt *November* to 1ſt *January*, the cold has increaſed about 8 degrees; and yet had the clock from 1ſt *January* to 10th *January*, almoſt the ſame motion, as from 1ſt *November* to the 16th; the difference of going being only $\frac{1}{55}$ of a ſecond.

This is a clear proof that the mechaniſm of the pendulum rods, and the biſected lens, lately invented by that renowned Artiſt, are generally ſufficient to prevent the great effects of heat and cold, and conſequently that the leſs important errors of this clock, cannot at all be meaſured by the increaſe and decreaſe of heat and cold. Without this precaution of the artiſt, the ſame degree of heat and cold might have a very different effect on the pendulum, on account of the different lengths of their duration; and ſeveral degrees of heat and cold frequently ſucceeding each other, would, in a given time, cauſe the ſame number of vibrations that a conſtant and fixed degree of heat would produce in the ſame time; whereby we might be led into great errors, and commend a faulty machine, as if it was juſt and regular.

There is one reaſon more why I hope you will approve the method I have choſen for examining the going of the pendulum. Had I, while making this trial, daily compared the actual degrees of the heat or cold, with the actual motion of the clock, I ſhould have been obliged to bring into the account all the minuteſt alterations of the air that happened in the ſpace of 24 hours, and the ſmall inaccuracies unavoidable in the obſervations of the ſtars, which would have rendered the matter much more dubious. In order to diminiſh the effects of theſe ſmaller inaccuracies, it was neceſſary to extend the compariſons I was about to make, to a larger ſpace of time; this I borrowed from the well-known method uſed by aſtronomers, for reckoning the mean and real motion of a heavenly body, and was certain it would bring me nearer the truth than any other; there appears to me a great reſemblance between the courſe of a heavenly body, and the going of a pendulum clock. *Arnold's* clock I conſider as a terreſtrial planet. The celeſtial planet is almoſt continually influenced by ſome diſturbing cauſe, in conſequence of which its motion is accelerated or retarded. The going of the clock is much more liable to be affected by various diſturbing cauſes. The planet, notwithſtanding all theſe obſtructions, deſcribes a curve of an oval form, returning into itſelf; the pendulum deſcribes a line of a ſerpentine form, which may be expreſſed by means of an hyperbola: hence the periodic revolutions muſt be of different lengths.*

If you aſk me what other cauſes occur which diſturb and vary the rate of the clock, I muſt acknowledge that great part of them are yet unknown to natural philoſophers. We are not ſure whether the ſame proportion always takes place between the increaſe and decreaſe of heat, and the increaſe and decreaſe of length in a metal rod. To illuſtrate my meaning; we ſay that a common iron bar, placed in a heat in which *Reaumeur*'s thermometer riſes 30 degrees, is lengthened about $\frac{1}{5}$ of a line; but I believe it has not yet been proved by experiment, that the intermediate degrees always cauſe a proportional increaſe of length in the rod: on the contrary we ſee, that by a certain increaſe of heat, hard metal is changed into a fluid body; conſequently there is a maximum in the power of extenſion of a metal bar; muſt there not alſo be a maximum in the contractive power of metals, after which the iron bar remains unaltered? Experience proves, that the extenſion of braſs is to that of ſteel as 121 to 74; but fortunately this, though it be a new cauſe of diſturbance to the motion of the pendulum, can have no great effect, though at different times there muſt be a different friction in the ſteel and braſs teeth at the principal wheels.

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* There ſeems to be ſome obſcurity in this part; the tranſlator frankly confeſſes that he cannot properly make out the ſenſe of the expreſſion, and has therefore inſerted the original text.

Der Planet beſchreibt; allen gemachten Hinderniſen ungeachtet, eine in ſich rückkehrende eiförmige Linie, die Pendeluhr durchläuft eine Schlangen-linie, welche durch eine Hyperbole kann erklärt werden; daher auch derſelben periodiſcher Zeitumlauf ſehr ungleich ſein muß.

The reſiſtance of the air in which the lens of the pendulum vibrates, is another cauſe of diſturbance in the motion; and this commonly operates more ſtrongly in winter than in ſummer. By experiments made in *France* and *England*, purpoſely to aſcertain the fact, it appears that the denſity of the air, from the greateſt heat in ſummer to the greateſt degree of cold in winter, is as 1 to 3. The famous *Muſchenbroek* fixes it as 1 to 2. Therefore, in ſummer the lens of the pendulum finds three times leſs reſiſtance than in winter. Theſe lenſes, fixed on the pendulum rod, are commonly filled with lead; and, notwithſtanding their power of gravity is leſſened at each vibration by the reſiſtance of the air, it is commonly thought that a cubic inch of lead is 11000 times heavier than a cubic inch of air; therefore the pendulum loſes in 24 hours $\frac{1}{11000}$ of its motion, and conſequently makes $7''\frac{1}{2}$ vibrations leſs in 24 hours than it would have made *in vacuo*; and that in the ſummer, when on account of the heat, &c. the air is about three times thinner, it will go nearly two beats faſter in 24 hours: if the lens was made of gold it would make about 4 or 5 vibrations leſs than *in vacuo*. This laſt cauſe of irregularity, which depends on the denſity of the air, cannot be removed entirely, either by the gridiron pendulum, or giving a greater circumference to the lens itſelf. *

My ſecond *Engliſh* pendulum, with a grate or gridiron rod, according to the form of *Norton*, furniſhes me with a circumſtance worth mentioning; as all the other pendulum clocks I have ſeen with like rods are on his conſtruction. The lens ſuſpended on the grate, when the heat increaſes, cannot extend itſelf downward on account of the ſcrew; but only upwards, by which the center of gravity is removed, and this removal has a neceſſary influence on the effects produced by ſeveral metal bars.

Theſe are the cauſes of the irregularities in the going of the pendulum, which the art of Mr. *Arnold* has endeavoured in ſeveral points to remedy. Though the lens filled with lead be ſplit in the middle, yet this lead has liberty to extend itſelf on all ſides equally. The croſs diameter of each of the pieces amounts only to 3 inches, and it is my opinion that, from the ſmallneſs of the ſuperficies, the pendulum gains more with regard to the changeable reſiſtance of the air, than it loſes by its diminution of gravity on account of the cut in the middle.

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* The Tranſlator has been informed that in the Pendulums *Mr. Arnold* now makes, this error is perfectly corrected.

You

You will now be much better able than before to comprehend the cauſes of the abovementioned ſmall inaccuracies of this pendulum. According to the firſt table, the greateſt variation happened from *December* 16 to *January* 1; at which time the clock went too faſt about 0″,27 in 24 hours, though it went about 0″,17 too ſlow in a much ſeverer cold, from the 1ſt to the 10th of *January*. Conſult the two firſt tables, and you will find an extraordinary alteration in the denſity of the air: 22d *December* the barometer was perceived to be fallen to 26 inches 6 lines, at which time the pendulum met with much leſs reſiſtance. At this time the whole alteration obſerved in the riſing and falling of the mercury was 14,3 lines. Compare the remaining obſervations made in both tables and you will eaſily perceive that the increaſing and decreaſing denſity of the air greatly influences the going of the pendulum, and ſoon be ſenſible that the pendulum clock muſt be regarded as one of the moſt excellent inſtruments for meteorological diſcuſſions; whence in future the doctrine of the air may be infinitely enlarged.

In my opinion, the principal aim ſhould be to diſcover how much thinner the air becomes when the barometer falls a line, and what effect that has on the going of a pendulum clock when the heat remains the ſame; for this purpoſe two common pendulum clocks might be equally regulated, and one of them be ſet in a high tower, where the height of the barometer ſhould be a line or two lower. The difference of the vibrations of both clocks in 24 hours would then diſcover to

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us almoſt the exact degree of the denſity and its effect. Only it muſt be obſerved, that theſe experiments ſhould not be made at two very diſtant places, nor in the neighbourhood of a chain of mountains, leaſt the ſtronger attraction of the earth ſhould interfere. It is likewiſe to be obſerved, that in two places of different heighths, the denſity of the air is inverſely as the ſquares of the heighths.

On this occaſion I muſt here mention another fact, which perhaps was never before obſerved; that the ſame degree of heat produces a quite contrary effect on the going of the pendulum. The heat, by lengthening the rod of the pendulum, renders its motion ſlower; but the reſiſtance of the air being leſſened in conſequence of its rarefaction by the heat, the motion of the pendulum gains in celerity. Again, the *cold* ſhortening the rod of the pendulum quickens its vibrations, but that is partly leſſened by the increaſed denſity of the air, and thus both irregularities are in ſome degree, though not entirely, corrected.

We may take both theſe oppoſite effects of the heat and cold into the account, provided we admit that the length of the iron rod increaſes and decreaſes in proportion to the degrees of heat and cold, for it is as the ſquare of the number of vibrations. If, when the heat increaſes 30 degrees in 24 hours, the number of vibrations is leſſened by 20; at 15 degrees increaſe of heat the vibrations will be reduced to about 14,14 ſeconds; at 10 degrees to about 11,4; and at 5 degrees to about 8,2 vibrations.

Again if we admit that equal increaſe of heat and cold, produces equal increaſe of rarefaction and condenſation in the air, and that as has been before obſerved, the pendulum rod *in vacuo* gives in 24 hours 7½ more beats; it follows that if the denſity of the air be doubled at an alteration of 30 degrees, the pendulum would again give 7½″ more beats, *i. e.* 15 vibrations more than before. From this we obtain the alteration of the going of the clock, at 30° and under as follows.

	°	″		″
For	30	24 — 20	+ 7,5	= - 12,5
	15	24 — 14	14 + 3,7	= - 10,4
	10	24 — 11	4 + 2,5	= - 8,9
	5	24 — 8	12 + 1.2	= - 6,9

We ſee hereby how far the rarefaction of the air, cauſed by heat, counteracts the too ſlow motion of the clock; this proportion is as 2,6 to 1 at an alteration of 30 degrees, as 3,8 to 1 at an alteration of 15 degrees, as 4,5 to 1 at an alteration of 5 degrees, provided the preſſure of the atmoſphere remained the ſame. The celebrated *Mr. Bouguer* found that in *Peru*, at the ſea ſhore, under the line where the height of the barometer was 28 inches 1 line, the length of the rod of his pendulum was 36 inches 7,07 lines; *in vacuo* he eſtimated it as 36 inches 7,21 lines. I found from the ſame author that the pendulum would perform 16½ more vibrations *in vacuo*, than in the open air: This experiment of *Mr. Bouguer* agrees with our calculation to one ſecond: the only difference is that the denſity of the air in *Peru*, was double of that which we have taken for our eſtimate.

Hence may be reſolved, the doubt ſtarted by the celebrated *Mr. Lambert*, who thinks the influences of the heat and cold, at 20″ for 30°. is marked too high, becauſe if the ſame cold ſhould continue a month, ſuch a clock would go too faſt about 10 minutes in 30 days, which is an irregularity too great not to have been mentioned, if it had really exiſted: but *Mr. Lambert* did not conſider the oppoſite effects of heat and cold.

The poſition adopted by the celebrated Monſieur *De la Lande*, that an alteration of 30 degrees in *Reaumeur's* thermometer, cauſes an alteration of 20 vibrations in the daily motion of the pendulum; is in my opinion founded upon the *Peruvian* experiments of *Mr. Bouguer*, who writes that the heat which cauſes an alteration of 3 degrees in *Reaumeur's* thermometer lengthens the pendulum about $\frac{2}{100}$ of a line, the conſequnce is that 30 degrees make about two, or a fifth part, but this is only in *Peru* under the equator, where according to the teſtimony of *Mr. Bouguer*, the variation of the barometer through the year, does not amount to much more than 2 lines, but not in our climate where the denſity of the air is frequently ſubject to ſo great a variation, as 5 or more lines in 24 hours: hence we ſee the cauſe, why even the common pendulum clocks on an equal duration of cold, cannot go ten minutes too faſt, as this would require the denſiry of the air to remain unaltered. If the increaſe or decreaſe of the denſity of the air correſponded to the alterations of the going of the pendulum, theſe might be aſcertained.

I made an experiment on purpoſe to determine this, as my ſecond tables ſhews ſo remarkable a difference between the mean height of the barometer, from 16th *October* till 1ſt *November*, and between the 13th and 30th *November*; the latter was 27 inches 1,9 lines, the former 27 inches 9,25 lines.

This difference of 7,5 lines height of the barometer, amounts according to my account in a fortnights time, to 4,9 ſeconds; and *Mr. Arnold's* clock muſt have gone ſo much too faſt towards the end of *November*, on account of the diminution of the gravity of the air, if the ſame degree of cold had at both times continued.

In this eſtimate I admitted with *Mr. Bouguer*, the greateſt reſiſtance of the air, $=16''$ when the barometer ſhews 28 inches 1 line, or 337 lines; I therefore found by the canon $\frac{16}{337}$ for the going of the pendulum in 24 hours 0,0474 ſeconds as an effect of the barometers height altered about a line, this gave me in a fortnights time for the alteration of 7½ line, in the height of the barometer, the above mentioned 4,9 ſeconds; and *Arnold's* pendulum clock would have ſhewn more, had not a cold 7 degrees ſtronger intervened, and compenſated for the decreaſing denſity of the air.

In the firſt table you will ſee that *Mr. Arnold's* clock towards the end of *November* was really too faſt one ſecond.

Perhaps theſe concluſions drawn from *Mr. Arnold's* pendulum clock, and the Peruvian experiments will not be found uſeleſs when it is attempted to inveſtigate the yet unknown theory of the denſity of the air. I hope my method does not diſpleaſe you.

When I ſee that in the courſe of a year, *Mr. Arnold's* clock will vary no more than 3 or 4 ſeconds, my expectations are raiſed, my pleaſure is extreme; hereby aſtronomers will have opportunities of diſcovering ſome ſtill unknown irregularities in the diurnal rotation of the earth round her axis, in whatever ſituation it may be through the whole year, at each diſtance from the *Sun*. Your great ſkill in Natural Philoſophy and Aſtronomy, lead me to hope that I ſhall receive from you ſome important elucidations on this head.

I am Sir, &c.

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